A Practical Decision Tool for Marine Bird Mortality Assessments

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Abstract

Given the rise in anthropogenic, environmental, and disease events contributing to marine bird mortality, there is a critical need to improve the rigor of mortality assessments. Deficits in data collection and mortality estimation can hinder a manager's ability to document event scales and inform population level impacts. Therefore, to inform decisions required during activities such as conservation status assessments or harvest management, organizations may choose to incorporate mortality assessments into response plans. Resources, capacity, and assets to assess mortality vary across jurisdictions (federal, state, Indigenous, local, etc.), and clear guidance to support mortality assessments is often unavailable or not clearly addressed. Here, we present a decision support tool to help managers identify and evaluate survey options to assess bird mortality in a diverse array of scenarios. The objective of the decision tool is to improve data collection and availability which will increase the ability to robustly estimate mortality, given situation-specific attributes and constraints. This decision tool is designed to guide the response when a mortality event is initially encountered and offers suggestions for assessment and reporting procedures in the absence of other guidance or to complement existing protocols. The decision tool is also meant to inform decision making for response determination and resource allocation. The tool facilitates examination of options for further assessment and monitoring which users determine by examining questions pertaining to species prioritization, mortality spatial extent, and the potential magnitude of impacts on affected species. Finally, identification of appropriate survey methods, that address imperfect detection when a complete census is not possible, are determined by exploring location, spatial and temporal extent, and the type of species affected. Ultimately, this tool aims to facilitate and improve the standardization of

mortality assessments, equipping managers with a practical resource to navigate the decision-making process for marine bird mortality estimation.

Keywords: seabird, mortality assessment, mortality estimation, standardized reporting, survey methods, at-sea surveys, shoreline transects, beached bird survey, response planning

Introduction

Seabirds represent one of the most threatened bird groups (Croxall et al. 2012), and their populations are especially vulnerable to increases in adult mortality because species are long-lived, have delayed reproduction, and produce small clutch sizes (i.e., slow life history). Threats to marine birds include climate change (e.g., marine heatwaves; Jones et al. 2018, 2024; Piatt et al. 2020), weather events; (i.e., prolonged storms which can induce starvation; Clairbaux et al. 2021), pollution (e.g., oil-spills, chemical pollution; Munilla et al. 2011), direct mortality via fishing bycatch (Lewison and Crowder 2003) and harvest (Naves 2018), negative impacts imposed by invasive species on nesting islands (Spatz et al. 2023), food stress, harmful algal blooms and other biotoxins such as botulism and disease (Descamps et al. 2012, Avery-Gomm et al. 2024). Consequently, many species with vulnerable populations are subject to multiple threats and have experienced or are at risk of significant mortality events (Dias et al. 2019). Given these numerous and escalating threats, improved mortality estimation is crucial for effective species management. True seabirds are highly adapted to marine environments and include species belonging to the taxonomic orders Pelecaniformes, Procellariiformes, Sphenisciformes and numerous Charadriiformes (Schreiber and Burger 2002). Here we expand the term “marine birds” and we include other birds commonly found feeding at sea and in coastal environments, either near or offshore, such as sea ducks, grebes, loons, and herons, which are commonly detected in seabird surveys (Nevins et al. 2011). We also include the numerous marine and coastal species that have significant inland populations, often found in wetlands, riverine, and lake habitats, or use inland habitat for breeding (e.g., Double-crested cormorants (*Nannopterum auritum*), Herring gulls (*Larus argentatus*), and Marbled murrelets (*Brachyramphus* *marmoratus*). Though our decision tool does not directly address inland habitats, it can readily be adapted to inland scenarios where similar threats and monitoring challenges exist.

Mortality events, including elevated mortality as compared to typical detections, large-scale or mass mortality events (MME), may involve larger than expected numbers of dead birds and may be significant relative to population sizes of the affected species (e.g., Camphuysen et al., 1999). The scale of mortality events may be defined differently depending on the analytical approach. For example, researchers have used long-term data series that helped define the "baseline" or usual level of mortality and then examine the departure from that baseline during mortality events to assess the magnitude (e.g., Jones et al. 2024). Without existing monitoring programs, baseline mortality levels may be poorly understood (refer to Parish et al. 2018). For some species (e.g., shearwaters of genus *Ardenna*), such increased mortality events are on the rise (Glencross et al. 2021).

Improved estimation of marine bird mortality, whether occurring at breeding sites or carcasses found on beaches, can support evidence-based conservation and harvest management decisions. Defensible mortality estimates can enhance the monitoring of population trends, assessment of species' conservation status, guide sustainable harvest regulations, inform impacts on culturally sensitive and subsistence harvest species, and ensure the release of quality information to the public. Additionally, defensible mortality estimates can be leveraged to support protection and restoration efforts as seen in Alaska, United States following the Exxon Valdez oil spill (Piatt et al. 1990) and in Israel during the highly pathogenic avian influenza (HPAI) H5N1 outbreak (CMS and FAO 2022). Improved documentation and estimation of discrete mortality events can significantly enhance population, regional and species-level abundance estimates. We propose that refining the methodology of mortality event estimation will yield more accurate data to inform and ultimately aid conservation and population management efforts.

Often no data on marine bird morbidity and mortality are collected or reported, limiting the information available for biologists and managers tasked with monitoring and managing bird populations. Procedures to estimate or even approximate (i.e., count based on incomplete information) affected birds, sick and dead, are difficult to develop during mortality events. Developing standardized procedures to assess and quantify mortality prior to events could improve our ability to respond in a timely manner and assess causes and impacts more effectively.

Few programs are in place to systematically quantify (i.e., to count or measure) dead and sick birds during mortality events and there is a lack of harmonized guidance on how to approach the selection of appropriate methods for the collection of mortality assessments. Mortality estimation is challenging due to the episodic nature of mortality events, which can happen almost anywhere and at any time (Camphuysen et al. 1999). Further, the number of mortalities detected in marine species may only be a tiny fraction of the total mortality (Burger 1993). This low detectability is often a function of at-sea mortality, which may result in carcass-sinking, scavenging and decomposition, reducing the opportunities for direct observation (Wiese 2003). In many true seabirds, low detection is further complicated by life history and behavioral characteristics, such as nocturnal activity, small body size, and cryptic coloration (Rodríguez et al. 2017).

Data collection during mortality events is often reactionary and ad hoc, yielding to messy data, which can result in incomplete data, collected through various methods, collected via non-standardized survey methods. Without a clear plan for how the data will be used to inform management strategies, collection methods may lack the necessary rigor to ensure the data are both usable and extrapolatable. This may lead to irrecoverable missing data that may hinder the identification of the cause or scale of mortality events (Glencross et al. 2021:2). Identifying the end user of data from the outset ensures that the data collection and survey design follow best practices, making the data more reliable and effective for conservation and management decisions.

Although systematic effort to quantify the number of carcasses may not reflect total mortalities, it provides a minimum estimate, serving as a baseline against which mortality figures can be adjusted according to the sampling design, such as the use of distance-based sampling to compute estimates. These records also help to assess whether a mass mortality event is impacting a significant portion of the population (e.g., >1%). Additionally, such data allow for the evaluation of the spatial and temporal aspects of the event, and information on factors like age and sex of the individuals offers a better understanding of the likely effect on the wider population.

Here we provide a multi-level decision support tool for decision-makers as well as on-the ground responders (e.g., wildlife biologists, rangers, technicians, other field personnel, etc.) who are responsible for the conservation and management of marine bird populations. The appropriate decision maker(s) may vary depending on the scale of mortality (e.g., from site specific wildlife managers to agency supervisors, etc.) and across regions and jurisdictions (e.g., local to federal, non-governmental organization (NGO), or multi-agency teams), responsible for the conservation and management of marine and inland bird populations. This tool guides the user through key decisions commonly encountered during mortality events, with the goal of helping to identify what actions may be necessary to produce scientifically defensible estimates of the species and numbers of birds affected. First, we provide a decision tree and a 'Mortality Event Documentation and Reporting' template to assist on-the-ground responders on the immediate collection of standardized and robust (i.e., less haphazard) data during the initial detection of a mortality event (refer to Initial Assessment of Mortality Event section; Tree A). Second, we provide a decision tree that supports the decisions as to whether further mortality assessments are warranted (refer to Follow-up Mortality Assessment section; Tree B). This guides the decision-maker in evaluating species prioritization, spatial extent of the mortality event, and the scale of its impact, helping them select the most appropriate survey method(s) to best estimate birds affected within constraints of resources. Finally, we discuss the assumptions and additional factors that could inform survey method selection, including resulting data quality and limitations in downstream analysis.

Positionality statement

The team for this project was made up of women and men from government, academia, and non-governmental organizations from the global north, including the USA, Canada, and the UK. We are trained as conservation ecologists, research scientists, seabird biologists, wildlife managers, epidemiologists and decision scientists. Although our tool is meant to serve to improve marine bird mortality assessments in any jurisdiction, it has been developed and evaluated with seabird populations in Atlantic Canada, Alaska, California and Hawaii in mind. Our tool and manuscript have been developed to address marine bird mortalities but could readily be adapted to address inland bird mortalities. Our tool is meant to be generalizable to any jurisdiction, however, we also include specifics related to jurisdictional authorities and agencies in the USA as an example.

Initial Assessment of Mortality Event (Tree A)

Marine bird mortalities may be detected by the public, wildlife rehabilitation centers, researchers, rangers, or field biologists. They may be reported to media outlets, on participatory science platforms (i.e., iNaturalist, https://www.inaturalist.org), on social media or through existing official organizational channels, such as online reporting tools which are increasingly available to jurisdictional authorities and agencies (e.g., WHISPers, https://whispers.usgs.gov/home). Implementation of broadened federal organizational response networks similar to the USA's National Oceanic and Atmospheric Administrations (NOAA) Marine Mammal Entanglement Network (https://www.fisheries.noaa.gov/national/marine-life-distress/national-marine-mammal-entanglement-response-networks) could be helpful in coordinating cross jurisdictional responses and improving data collection and sharing. However, broader tools for the public to report total numbers of sick and dead birds are needed. These various routes of detection reports require a decision-maker, of the appropriate jurisdiction depending on the locality, to follow-up and determine the need to initiate an investigation.

The procedures to quantify sick and dead birds (hereafter, collectively termed 'mortality') during the initial detection of a mortality event are often unclear or not prioritized. This can hinder follow-up activities because initial detection may be the best opportunity to accurately estimate total mortality numbers, geographic scale, and the duration as well as the ability to collect information that could reveal the causative agents or events leading to mortality. Information collected early in a mortality event is also essential to informing subsequent decisions (i.e., follow-up mortality assessments, reallocation of resources).

Initial Assessment of Mortality Event

'Initial Assessments of Mortality Events' (Fig. 1) are most valuable when accompanied by collection of samples to evaluate (e.g., necropsy and/or other diagnostics) the cause and when including proper documentation of the species and number of birds impacted along with the spatial extent of the mortality event. When a mortality event occurs in remote areas, the initial assessment may provide the only opportunity to quantify and describe the event.

If capacity (i.e., time, personnel, funding, logistical resources) is sufficient to comprehensively and safely identify and count all sick and dead birds (Figure 1, A.2), personnel may follow protocols conveyed within existing organizational response plans or in the 'Mortality Event Documentation & Reporting Template' (refer to existing response plans and/or Box 1 to determine ability to safely quantify mortality). However, there are many reasons that the capacity to comprehensively census mortality during an initial assessment may not exist. For example, there may be too many carcasses to count, carcasses may be distributed over an area too large to survey given the resource capacity, mortality may be at areas so remote such that timely response by trained personnel is not possible, or the health and safety of personnel may be a factor (i.e., lack of diagnostic collection training, access to personal protective equipment (PPE), unsafe site access or conditions) (Fig.1, A.1). If timely response is possible and human health and safety considerations permit an alternative to a complete census is to estimate the number of sick and dead birds along with the total area where mortalities have been confirmed (Fig. 1, A.3). If the area is too large, then representative subsamples may be conducted by identifying and counting individuals along transects or within a defined, representative area, taking into account the extent of the mortality event (Fig. 1, A.3). The percentage of the total affected area that the transects/sampled areas represent should be reported (Fig. 1, A.3; Box 1, Step 2.5b). Transects and total affected area can be determined by taking geographic coordinates or marking approximate locations on a map. Collecting the data indicated within the ‘Mortality Event Documentation & Reporting Template’ will provide critical insights into the extent and distribution of sick and dead birds while also providing event boundaries and survey effort (i.e., person hours). To improve our ability to assess the impact of mortality both as isolated geographic incidents and on population or species-wide scale, wildlife managers can amend existing response plans to incorporate data collection and steps outlined in the ‘Mortality Event Documentation & Reporting Template’ (Box 1).

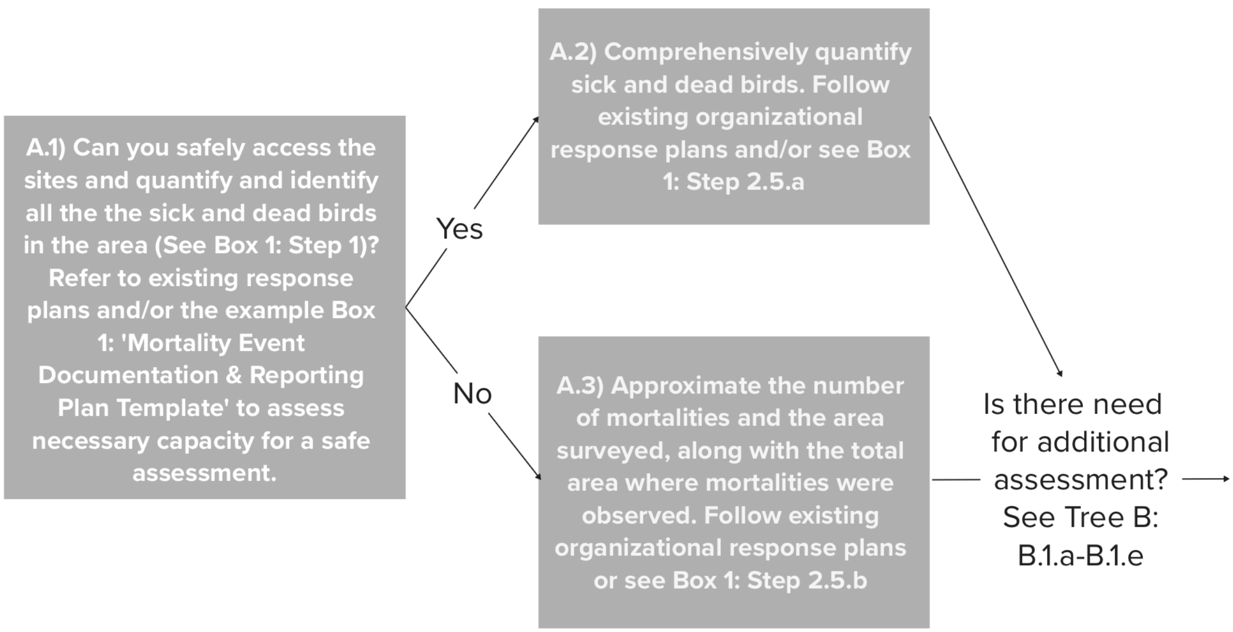


Fig. 1) Decision tree A- Initial Assessment of Mortality Event. The initial mortality assessment includes determining the extent of marine bird mortality and capacity for enumeration or approximation. All assessments benefit from the inclusion of documentation and reporting and may benefit from sample collection where trained personnel are available to collect samples promptly after detection following organizational protocols. The ‘Mortality Event Documentation & Reporting Plan Template’ below serves as an example to illustrate the types of

information that should be collected during the Initial Assessment of Mortality Event. It may be used in conjunction with or in absence of existing organizational response plans. Tree continues in Fig. 2.

Box 1. Mortality Event Documentation & Reporting Template

STEP 1: Assess field safety for personnel

The first step during a response is assessing the ability of personnel to collect information safely. This includes assessing the field site to determine whether/how information can be safely collected. If needed, confirm that personal protective equipment (PPE) and decontamination materials are available (Taylor and Buttke 2020). Modify response as necessary based on location, material limitations, or other safety considerations, along with the level of risk posed by the event and its causative agents.

STEP 2: Document essential information

Documenting the extent of disease, toxicosis, and/or mortality is a second critical step in an effective response. In the absence of an existing organization protocol for documenting morbidity/mortality, the collection of the following information will be useful for documenting the extent of a mortality event.

2.1 Record the date and time the mortality event was first encountered and the estimated time of onset (if different) and any data supporting this timing (such as freshness of carcasses, etc.).

2.2 Record clinical signs (e.g., symptoms) displayed by dying birds (e.g., tremors, neurologic signs, unresponsiveness, inability to walk or fly, oiling, etc.…). Document with videos or photos if possible. If time of mortality onset was estimated, describe how it was estimated.

2.3 Record other potentially useful observations that may indicate mortality source (e.g., distribution of mortalities, derelict fishing gear, oil/other pollutants on shore, other dead species such as fish or marine mammals, 'red tide' observed in the area, recent weather events such as cold fronts, high seas, strong winds, etc.). Include site photos, showing affected species and surroundings, when possible.

2.4 Record the area delineating the event as far as possible. Mark event boundary extents and transect/survey start and end locations on a map or take notes if precise geographic coordinates are not immediately available. Map locations and/or take detailed note descriptions of locations that can be used to obtain approximate locations *post-hoc*.

2.5 Quantify sick and dead birds. To prevent double counting carcasses may be marked (i.e., with water soluble spray pain or tagged) or removed, depending on safety, resources, and logistics. Marked carcasses can be further evaluated for carcass persistence rates when possible.

2.5.a If feasible, *comprehensively quantify* mortality by surveying the entire affected area and record the following as possible: species present identified to the lowest taxonomic level possible (Hass 2002); number of each species or taxonomic unit found sick (exhibiting any illness symptoms, such as lethargy, impaired movement, respiratory rate, neurological, etc.), dead or alive (not sick/effected); sex/age class (to differentiate adults and chicks during the breeding season; any additional data needed to characterize events such as state of decomposition, location of mortality (wrack line, in colony, buried in sand), signs of illness, pollution detected, etc..

2.5.b If not feasible to survey the entire affected area, estimate the number of mortalities by using a statistically designed strategy to subsample the sick and dead birds, such as distance-based sampling methods (refer to Discussion for more). Record the following: positions for the start and endpoints of any transect, species present identified to the lowest taxonomic level possible; number of each species or taxonomic unit found sick, dead, alive (not sick/effected) in representative transect or area. Estimate and record the percentage of the affected area that the transect/sampled area represents (e.g., 1-100%).

2.6 Record the date/time and effort (e.g., person hours, number of surveyors) per transect(s)/survey(s). Document the status of the event, ongoing/chronic or apparently resolved/acute or unknown, and any supporting data.

STEP 3: Initiate communication and coordinated efforts

Communication of a mortality event should follow existing organizational guidance. In the absence of an existing organizational plan for communication, the following examples are provided for the USA, though this approach may be adapted to any jurisdiction. In general, and as appropriate in specific jurisdictions, the environmental and wildlife management agencies, wildlife veterinarian and landowners should be contacted. Other agencies and non-governmental organizations may be involved if an event has human health or environmental safety impacts. Surveillance and data reporting may require local to federal involvement. Large-scale or complex outbreaks/events necessitate improved regional cooperation across levels to inform and initiate coordinated efforts.

3.1 Communicate observations of mortality first to appropriate levels of leadership within the organization and seek guidance before communicating outside of the organization. Prioritize conveyance of quantitative and qualitative information collected in STEP 2.

3.2 As appropriate in the USA, contact the federal and state wildlife management agencies, the local land management agency (or private landowner), the State Veterinary Office, and/or U.S. Geological Survey (USGS) National Wildlife Health Center (in this order). Outside of the USA, consider a similar approach for informing appropriate local, provincial, territorial, regional, and national contacts. Prioritize conveyance of quantitative and qualitative information collected in STEP 2. Obtain and confirm guidance on collection of samples for diagnostic testing (STEP 4) and decontamination protocols (STEP 5).

3.3 Seek guidance before initiating additional communication outside of organization. Develop and refine messages to inform and educate partners and/or the public of the mortality event as appropriate. Messaging should emphasize the importance of public health and safety, including recommendations against possible exposure and risks, such as avoiding contact with dead or dying birds, keeping pets on leashes and away from carcasses to prevent potential spread of disease or toxins, and reporting sightings of affected wildlife to appropriate authorities. In the USA, messages should typically be coordinated with concurrence of organizational leadership and the state or federal land management agency (or private landowner), the State Veterinary Office, and/or the USGS National Wildlife Health Center and may involve human health agencies, including One Health representatives. Outside the USA, a similar approach involving appropriate local, regional, and national partners in the development and conveyance of messages may be appropriate.

STEP 4: Collect samples to diagnose the cause of death

Per organizational guidance and/or communication in STEP 3, collect carcasses and/or samples for diagnostic testing. Personnel safety and existing organizational guidance should be considered before the collection of diagnostic samples for a wildlife mortality event. This includes the identification of the sample type needed to identify the mostly likely diagnoses given the unique context of the event. Before collecting carcasses/samples confirm that personnel are properly trained to collect samples, personnel are equipped with appropriate PPE, proper sampling and decontamination materials are on hand, disposal methods are appropriate to reduce future contact of humans with carcasses (e.g., double-bagging), that the samples can be maintained through a satisfactory cold chain such that biological products are kept at their target temperature, and an appropriate diagnostic lab is available and willing to receive samples, or that samples can be safely stored in a dedicated freezer for later testing.

STEP 5: Decontaminate equipment (as applicable)

If response to a mortality event involves water- or land-based survey of an affected area and/or the collection of diagnostic samples, take steps to decontaminate equipment, personal gear, and properly dispose of PPE to protect human and animal health. Adjust decontamination protocols accordingly for different causative agents.

Follow-up Mortality Assessment (Tree B)

Information gathered during the 'Initial Assessment of Mortality Event' (Fig. 1, Tree A) will help wildlife managers to determine whether further assessment is needed in order to develop scientifically rigorous mortality estimates through standardized and/or statistically designed surveys (Fig. 2, B.1.a - B.1.e). If there is need, the decision tree guides the user through identifying the most appropriate survey methods given the mortality event location (Fig.2, B.3).

Producing improved mortality estimates require attention to appropriate survey design, implementation of standardized procedures, and the skills to integrate various data types to produce defensible estimates. Mortality estimates can be strengthened when ecologists with strong quantitative skills, particularly in survey design, wildlife biologists, and biometricians collaborate on survey design. The scale of bird mortality, along with the geographic, environmental, and temporal complexities of each event coupled with the available resources and capacity, collectively inform the suite of response and estimation methods that can be applied. These factors ultimately influence the robustness of the mortality estimate which generally provides a conservative estimate of mortality. Accurate mortality estimates are not possible in most cases of marine and aquatic birds due to the likelihood of at-sea-loss and low detection probabilities.

Determining Need for Further Assessment (B.1.a -B.1.e)

Follow-up assessments may be recommended for various reasons. These include the determination that the species affected includes a high-priority species (Fig. 2, B.1.a), such as those with listing or conservation designations (e.g., Critically Endangered, Endangered, Vulnerable, Threatened or Near Threatened; Categories vary by designating body), internationally (i.e., by IUCN), federally, (e.g., under the USA's *Endangered Species Act* and/or Canada's *Species at Risk Act*), or other status designations (e.g., regional, tribal, provincial, territory, and state) (Table 1). A species may be prioritized if it has cultural value, or if it supports regulated or subsistence harvest. Even a common or non-threatened species, such as Canada geese (*Branta canadensis*), may be prioritized if a mortality event has potential population level consequences. Particularly if the species presently affected may overlap in habitat with high priority species. A species may also be prioritized at a decision maker's discretion. For example, prioritization may occur if regional species status designations (i.e., state, provincial, tribal, or specific land unit, such as National Wildlife Refuge in the USA) or local knowledge suggests a follow up mortality assessment is worth further consideration. Here categories 2a - 2g (Table 1), using Alaska, USA as an example, illustrate proposed high priority species, such as critically endangered Leach's storm petrel (*Hyrdrobates leucorhous*; IUCN designation). Conversely, low priority species include those of least conservation concern, as designated by the IUCN and overabundant species (examples in Table 1, categories 2.h and 2.i). An overabundant population is one whose populations result in ecological disequilibrium and negatively impact habitats and the ecological community, such as degradement and declines of other native populations (Goodrich and Buskirk 1995).

The scale of the event, whether due to its geographic extent or the sheer number of carcasses reported, may necessitate further mortality estimation to inform management (Fig. 2, B.1.b- B.1.c), even if it involves lower priority species (Table 1, 2.g – 2.h). The cause of the mortality event may also necessitate further estimation (Fig. 2, B.1.d), especially if the cause is identified to be ongoing or chronic in nature, with continuing mortality expected. Factors to consider include the likelihood of multiple habitats being affected, the probability of recurring events requiring repeated visits/assessments, and the potential for a broad number of detections across a complex spatial landscape/seascape. For example, mortalities resulting from infectious diseases, such as HPAI, might be a priority for further mortality estimation due to the potentially large disease burden on the landscape and an affected species' ability to transmit the disease to other species and habitats. In such scenarios where intensive monitoring exists and continuous surveys are possible to monitor chronic events, mortality estimation may provide age-class specific mortality curves for the extent of the mortality event (Haman et al. 2024). In the case of chronic mortality events, it may be necessary to determine how to deal with carcasses, removal versus tagging, to determine the proportion of new carcasses upon each visit. If circumstances suggest the cause of the event is emergent or unprecedented, such as where species exhibit unusual behaviors or symptoms, this may provide rationale for further assessment (Nevins et al. 2011).

If the extent of the mortality event and species affected do not necessitate further assessment, then initial assessments of a mortality event may be sufficient. If the user finds the answer to all the questions posed in B.1.a- B.1.e (Fig. 2; i.e., priority species, extent and scale of event, continued risk of mortality, or significant population impacts) is 'no', then the mortality event may have been sufficiently assessed (Fig. 2, B.2). Conversely, if any of the answers are 'yes', the user is guided to continue exploring the tree (Fig. 2, B.3).

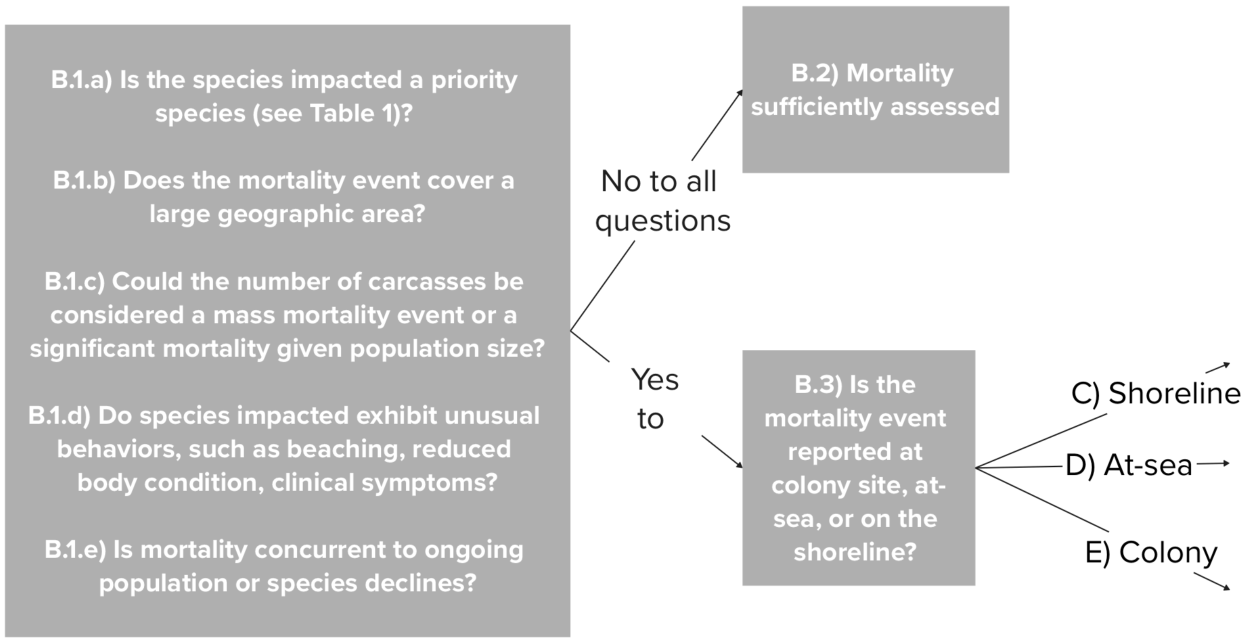


Fig. 2) **Decision Tree B- Follow-up Mortality Assessment:** Determining whether there is need for further assessment through use of criteria of questions B.1.a – B.1.e for the mortality event, including priority species determination (further detailed in Table 1), geographical extent and scale of mortality, characteristics to identify mortality events that exceed baseline or expected levels of natural mortality, and species experiencing population declines. If further assessment is suggested, 'yes' to B.1.a – B.1.e, than the tree continues in Fig. 3, Tree C- E.

Table 1) Species categories for prioritization and mortality assessment follow-up. The table outlines species categories used to determine prioritization (high or low) for mortality assessment, along with examples of species for Alaska, USA, which do not represent a comprehensive list. In this context, categories 2a – 2g are deemed high priority, while categories 2h - 2i are considered low priority for further assessment. These categories include species designated as Critically Endangered (CE), Endangered (E), Vulnerable (V), Threatened (T), Near Threatened (NT), Birds of conservation Concern (BCC), of the Endangered Species Act (ESA) and Species at Risk Act (SARA), as implemented by IUCN, USA, or Canada. Species lists are subject to change over time and by region as data and species conservation statuses are updated.

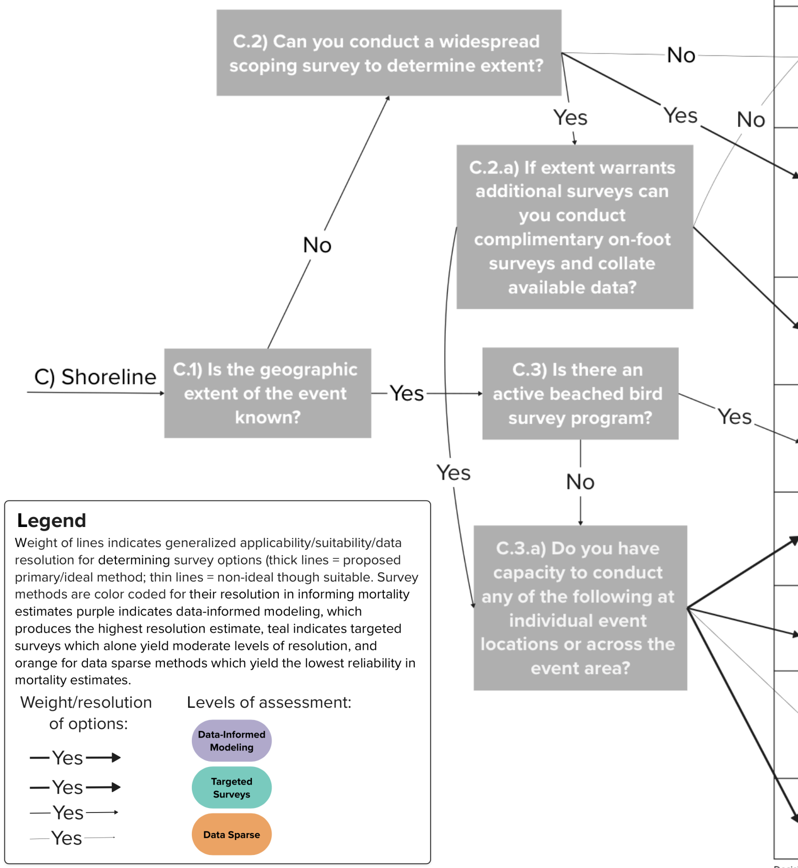
SPECIES (Spp.) CATEGORY	**PRIORITY**	**EXAMPLE SPECIES**
2a) Listed spp. CE/E/SARA	High	Short-tailed Albatross (*Phoebastria albatrus*), Pink-footed Shearwater (*Puffinus creatopus*)
2b) IUCN vulnerable	High	Leach's Storm Petrel (*Hydrobates leucorhous*)
2c) Harvested spp.	High	Brant (*Branta bernicla*), Surf and Black scoters (*Melanitta perspicillata* & *Melanitta americana*)
2d) Spp. of cultural value	High	Emperor Goose (*Anser canagicus*)
2e) Subsistence harvest spp.	High	Crested and Least auklets (*Aethia cristatella*, *Aethia pusilla*), Common and Thick-billed murres (*Uria aalge*, *Uria lomvia*), Short-billed Gull (eggs; *Larus canus*)
2f) Mortality has potential pop. level effects, T/NT/BCC	High	Spectacled Eider (*Somateria fischeri*)
2g) Spp. prioritized by decision-maker	High	Yellow-billed Loon (*Gavia adamsii*)
2h) IUCN least concern	Low	Double-crested Cormorant (*Phalacrocorax auritus*)
2i) Overabundant spp.	Low	Glaucous-winged and Herring gulls (*Larus glaucescens*, *Larus smithsonianus*)

Location of Mortality Event Detection (B3)

Shoreline Detections (Tree C)

Mortality events are often first detected when marine bird carcasses wash ashore. To determine which survey methods are most appropriate for estimating number of birds affected, it is essential to first consider the geographic extent of the event (Fig. 3, C.1) and whether the extent of mortality can be captured (Fig. 3, C.2 – C.3).

If the geographic extent of the mortality event is known (Fig. 3, C.1) and an 'active beached bird survey' program exists (Fig. 3, C.3), such as COASST (Coastal Observation and Seabird Survey Team, https://coasst.org)/ or other existing community or government-led monitoring programs these may be leveraged to assist in the mortality assessment where possible. However, frequency and survey strategy may need to be altered to get a better estimate of mortality. When no existing beached bird survey program is in place, other ground survey methods, such as 'shoreline transects', or 'single beach survey' (Fig. 3, C.3; detailed below), may be appropriate options depending on capacity and resources. In selecting the most appropriate survey method, several factors should be considered, including the number of mortalities, detectability of species, and site access (Fig. 3, C.3.a). Alternatively, when the geographic extent is unknown and there is capacity for further assessment, an 'aerial survey' or a boat -based 'near-shore survey' should be considered (Fig. 3, C.2, Yes). These methods can help to determine the extent of the event, the species affected, and the number of carcasses. Upon determination of the event extent, and if the extent warrants further assessment, then ground surveys or additional data collection (Fig. 3, C.3.a) may be conducted. If surveys cannot be undertaken then implementation of 'collation of reported mortalities' should be conducted, which includes collection of sick and dead birds reported to officials, by the public, NGO's, the iNaturalist platform (https://www.inaturalist.org), and all other public reporting platforms used in the region. If 'aerial' or 'near-shore' surveys cannot be mobilized to determine the extent of the mortality event, a viable option may be to conduct a '*public reporting and scoping'* assessment (Fig. 3, C.2, No). '*Public reporting and scoping*' require contacting as many potential sources, additional to those captured through '*collation of reported mortalities*', to the event region(s). These differ from collation by requiring further effort to collect information across various sources, such as industry, private landowners, and tourism operators within the potentially affected region to gather detections that were not reported (Avery-Gomm et al. 2024).



Survey Method	Description	Considerations
Public Reporting/ Scoping	Requires contacting all potential sources of mortality information, coast guard, fishing industry, tourism, sources for potential sea vessels in the region, local manages, private landowners, NGOs, academic researchers, and iNaturalist. Collect and collate reports of mortality from all available sources. Similar to collate reported mortality below but requires more effort to source information directly from all possible stakeholders in the region.	Requires staff capacity to contact all potential sources of information in the widespread region and collate and quality control data. Pros: May not require site visit. May be less expensive. Cons: Certain to result in underestimation. Extent of mortality may not be fully detected/ estimated.
Aerial Survey	Use of distance sampling via strip transect where aircraft (helicopter, plane or drone*) flies along shoreline and paired trained observers count carcasses (*observers review recorded footage) on both sides of the aircraft within a set perpendicular width using standardized protocols. See Camphuysen et al. 2004 for more information on survey methods.	Aerial surveys most appropriate for large body size/distinct plumage to the substrate. If conducting a shoreline/transect or beached bird survey at the same time you can then develop a correction factor*. Pros: Larger areas can be surveyed in a shorter period of time. Aircrafts can be used to survey areas that are difficult to access, complex coastlines. Cons: Aerial surveys have reduced species identification accuracy. Costly approach that is challenging to rapidly mobilize. Assumptions: Availability of deployable assets (helicopter, floatplane, drones) along with trained observers and personnel, and associated financial resources.
Near-shore Survey	Use of distance sampling via strip transect from a near-shore vessel (skiff, zodiac, etc.) where trained trained observer(s) travel along transects and count carcasses on shore, identifying species, and following standardized protocols. See Camphuysen et al. 2004 and Ronconi and Burger 2009 for more information.	Pros: May provide higher accuracy species identification than aerial surveys. Cons: Some locations may be limited due to remoteness or inaccessible due to shallow, complex, or high-energy coastline making aerial surveys the appropriate method. Costly approach that is challenging to rapidly mobilize. Assumptions: Deployable assets (vessel), trained observers and personnel, and financial resources are available.
Active Beached Bird Survey	Survey program (community, federal, or local) where individuals are assigned survey beaches or extents from point x to y. Survey is conducted on foot, wandering up and down the beach between high tide and the wrack line to count all birds, and repeated at intervals necessary to capture the temporal extent of mortality. Standardized protocols exist and vary by survey organizer.	Carcasses should be marked or removed to prevent double counting. Pros: Existing program structure. Can be conducted by trained volunteers or personnel. Cons: Mortality up the shore may be missed Assumptions: The existing survey captures the spatial and temporal extent of the mortality event.
Shoreline Transects	Distance sampling method with standardized protocol. Count everything within X meters of each side of the line transect. Include low tide to the wrack line (up the beach), possibly along the wrack line.	Best method for large numbers of birds on a single beach. Assumes shoreline access. Control for double counting (i.e., marking counted birds). Pros: Covers a broader range of the shoreline than other methods. Comprehensive method for estimating moralities. Cons: Requires staff capacity, ability to follow standardized protocols.
Single Beached Bird Survey	Survey method where individuals are assigned survey beach or extent from point x to y. Conducted on foot, wandering up and down between the high tide and wrack line to count all birds.	Less structured protocol than shoreline transects. Assumes shoreline access. Control for double counting (i.e., marking counted birds). Pro: This survey method is very suitable for volunteers. Cons: May miss detections as does not assess the beach perpendicular to the shore.
Collate Reported Mortality	Collate reports of mortality from all available sources. This may include federal, state/provincial, Indigenous, and municipal government staff and databases, NGOs, academic researchers, and iNaturalist. Observations of wild bird mortalities on seabird colonies may be gathered through direct solicitation from government biologists and academic researchers.	Requires staff capacity to collate and quality control data. Pros: May not require site visit. May be less expensive. Cons: Certain to result in underestimation. Extent of mortality may not be fully detected/ estimated.
Drift Modeling to Estimate At-sea Loss	Field experiments involving drift blocks or simulation modeling may be used to estimate what proportion of carcasses ground given conditions.	Pros: May be used to develop a correction factor of at sea loss of carcasses (i.e., those that do not make it to shore) when conducted in conjunction with on-foot surveys. Cons: Requires capacity to deploy and monitor blocks grounding. Simulations require that current, wind and particle movement models exist for the area.

Decisions as to the determination of the 'best' shoreline survey method depends on situation specific information (area of size impacted, numbers of birds), detectability of birds (i.e., whether large white or small black birds are involved), how the site is accessed, how clustered the mortalities are in space and time.

Fig. 3) Decision tree C- Shoreline detections: Survey options for assessing a mortality event for sick and dead birds detected in the shoreline environment. Survey decisions depend on the extent of the mortality, availability of active beached bird programs, and hinge on the ability and resources to conduct various survey methods. An alternative to surveys might be collation of existing data and/or additional scoping of 'public' data.

Marine bird mortality surveys can be conducted using various methods, including '*aerial surveys*' from aircraft or drones, '*near shore surveys*' from vessels, and shored-based beach surveys, each tailored to specific environments and logistical conditions. *'Aerial surveys'* which follow distance sampling protocols via strip transects, where aircraft, (helicopter, fixed-wing aircraft, or drone), fly along the shoreline and paired trained observers independently count carcasses; alternatively for drones, observers review recorded footage. 'Aerial surveys' may be a useful alternative for remote or complex coastlines with limited accessibility. *'Near-shore surveys'* also employ distance sampling via strip transects, conducted from a near-shore vessel (Tasker et al. 1984). *'Near-shore surveys*' may be necessary in areas where there is no beach, such as along cliff-faces, inaccessible rocky coastlines, or exposed high-energy coastlines. Trained boat-based observer(s) travel along transects and count carcasses on shore, identifying species, and following standardized protocols. Refer to (Camphuysen et al. 2004) for more information on survey methods. In specific situations, a simpler '*single beached bird survey*' may be implemented to assess mortality. Beached bird surveys differ from ground-based shoreline transects in that they generally do not follow distance sampling techniques, though they typically assess a pre-defined shoreline segment. Typically, in beached bird surveys, trained volunteers (often community members) or staff walk the beach in a meandering fashion, reporting live and dead birds (Nevins et al. 2011). The less structured protocols of '*beached bird surveys'* make them more easily implemented via finding volunteers and/or staff to train and run surveys. '*Beached bird surveys'* are commonly utilized for oil spill response and standard pollution and mortality monitoring (Camphuysen and Heubeck 2001).

'Aerial surveys' or *'near-shore surveys'* can be conducted in conjunction with ground surveys, either '*shoreline transects'* or '*beached bird survey*s', in order to develop a correction

factor. A correction factor accounts for differences in detectability (Munilla et al. 2011) due to the limitations of '*aerial surveys'*. Additionally, the ability to conduct an '*aerial survey*' may be limited by resource availability, including human (e.g., trained observers or licensed pilots), financial, and deployable assets (i.e., helicopter, plane, vessel). '*Shoreline transects*' are a distance sampling method which standardizes distance, and therefore total area, around the transect line where detections are counted and can be used to develop mortality estimates (Buckland et al. 2001). Transect surveys may be set to follow the wrack line, where seaweed is deposited, or perpendicular to the beach to cover various deposition points (low tide to high tide). Carcasses are typically either marked or removed from the beach to prevent double counting. Marking carcasses allows for calculation of persistence rates, which may vary with body size and local conditions (Van Pelt and Piatt 1995, Varela et al. 2015). At best, persistence rates can be estimated, but at a minimum, this method prevents the double-counting of carcasses. However, if carcasses are not detected early, species identification may be difficult. Interval times between carcass deposition and surveys may result in reduced persistence and detection, due to deterioration, scavenging, or becoming buried as occurs on high energy or catchment beaches (Burger 1993). Distance based '*shoreline transects*' are quantitatively the most rigorous option for on-foot surveys as they allow for the development of detection rates and carcass persistence rates. However, '*shoreline transects*' require staff capacity that are trained in bird identification, standardized protocols, and data collection.

Given that a large proportion of mortalities occur at sea and often only a fraction of these is washed ashore and detected, a common method of correcting mortality estimates of ground survey methods, either 'shoreline transects' or *'beached bird Surveys'*, is to develop a correction factor to estimate at-sea losses. A commonly used method is to use '*drift modeling'* approaches, such as deploying weighted drift blocks, which are created to mimic bird buoyancy or marked carcasses, that can be deployed offshore or at known mortality sites and the proportion detected at nearby surveyed beaches can be used to estimate deposition rates (Wiese and Jones 2001). Additionally, telemetry deployed on drift blocks or marked carcasses can shed light on drift patterns, deposition rates on shore, and loss at sea estimates to improve overall offshore mortality estimates (Martin et al. 2019). The use of drift blocks or carcasses may often not be feasible due to limited resources and capacity. Alternatively, drift simulations can be implemented post hoc using oceanic and climate data derived from satellite data and numerical models, these data where available may include current, wind, and particle movement models for the area of interest. In some regions unavailability of data may limit the ability to run simulations.

If no on-foot survey methods are possible then '*collate reported mortality*' is another option for obtaining additional information on mortality extent. Reported mortalities may include all reports provided to local, state, federal, tribal authorities and other relevant conservation organizations, data from the initial detection and mortality report(s) (i.e., sample testing and diagnostics), along with any available community science data such as iNaturalist records or the Local Environmental Observer (LEO) Network (https://www.leonetwork.org) for the area and time of the event. This approach does not require an in-person site visit; however, it requires staff capacity to collate and quality control the data (e.g., remove any duplicate records). Of the methods presented, '*Collation of mortality reports*' is likely to yield the lowest data accuracy and may result in a greater underestimation of mortality. This is because these reports are often opportunistic, and subject to inherent biases- for example, certain species may be more noticeable and thus more frequently reported, or urban centers with more observers may be overrepresented compared to remote regions with fewer observers. Due to these and other factors, it is challenging to accurately estimate the ratio of sick and dead birds reported by the public relative to the actual numbers affected. Therefore, for most species, except those already under intensive monitoring, such as certain populations of Roseate or Caspian terns (*Sterna douglii*, *Hydropogne caspia*), estimation efforts will generally provide only a minimum estimate of birds affected.

Water Detections (Tree D)

Mortalities may be detected in the water, as seabirds are often found across marine environments, from nearshore to pelagic zones. Mortality events detected on the water limit viable survey methods to two options: 'A*erial at-sea'* and *'Vessel at-sea surveys'* (Fig. 4). Both survey-methods require trained observers which record the numbers and species of carcasses they see. 'Aerial At-sea surveys' can be conducted via helicopter, fixed-wing aircraft, or drones, however deployability of these assets along with trained personnel may be logistically complex (Giralt Paradell et al. 2023). Both 'a*erial at-sea'* and *'vessel at-sea surveys'* are most rigorously conducted by incorporating standardized distance-based protocols including speed and altitude (Camphuysen et al. 2004, Buckland et al. 2008, Certain and Bretagnolle 2008, Ronconi and Burger 2009). Ocean conditions should be recorded during at-sea surveys to account for the effect of waves, current direction and velocity, wind speed, glare, and water quality on carcass detectability (Ronconi and Burger 2009).

As with shore-based surveys methods, detection of carcasses at sea is complicated by species-specific differences in detectability. Larger-bodied species with contrasting plumage to the substrate (e.g., large gulls) generally have higher detectability across survey methods, whereas smaller-bodied species with dark or cryptic plumage (e.g., murres, dovekies, puffins) have reduced detectability (Fifield et al. 2017). At sea, diving birds have reduced detectability due to their neutral buoyancy, which causes them to float lower in the water compared to soaring species, which have higher buoyancy (Ford et al. 1987, Hope et al. 2018). Moreover, carcasses may sink before detection, be removed by scavenging, or may deposit on shorelines. Sinking rates vary with body size, body condition and oil exposure (Wiese 2003, Castege et al. 2007). Loss in buoyancy over time causes carcasses to sink and affects offshore mortality detection, which may result in underestimation if not accounted for. Scavenging of carcasses shortens on-water carcass persistence, reducing detection, and increasing sinking rates as carcass buoyancy becomes compromised with scavenging (Wiese 2003)

Requirements for at-sea surveys include the availability of trained marine bird observers, licensed and trained vessel or aircraft personnel, financial support, and the necessary deployable assets capable of accessing proposed survey sites (i.e., helicopter, fixed-wing aircraft, drone, skiff, zodiac, etc.). Both aerial at-sea and vessel at-sea surveys may be costly and difficult to rapidly mobilize. However, '*aerial at-sea surveys*' can generally cover larger spatial extents in shorter periods of time, including complex coastlines or otherwise inaccessible regions (Fraser et al. 2022).

D) In Water

Survey Method	Description	Considerations
Aerial At-sea Surveys	Use of distance sampling via strip transect where aircraft (helicopter, plane or drone) flys parallel tracks, of standardized distance and interval, and paired trained observers count carcasses on both sides of the aircraft or from photographs. Strip widths may be made narrower when visibility is reduced due to conditions impacting detection. See Camphuysen et al. 2004 for more information on survey methods.	Aerial surveys most appropriate for large body size/white plumage species. Pros: Aerial survey can be completed in a shorter period of time as compared to at-sea vessels. Aircrafts can be used to survey areas that are inaccessible to ships, such as shallow seas and complex coastlines. Cons: Aerial surveys have reduced species identification accuracy. Costly approach that is challenging to rapidly mobilize. Assumptions: Deployable assets (helicopter, floatplane), trained observers and personnel, and financial resources are available.
Vessel at-sea surveys	Use of distance sampling via strip transect from an at-sea vessel where trained paired observer(s) travel along transects and count all carcasses on each respective side of the vessel, identifying species, and following standardized protocols. See Camphuysen et al. 2004 and Ronconi and Burger 2009 for more information.	Pros: May provide higher accuracy species identification than aerial surveys. Cons: Some locations may be limited due to remoteness or inaccessible due to shallowness or complex coastline making aerial surveys the appropriate method. Costly approach that is challenging to rapidly mobilize. Assumptions: Deployable assets (vessel), trained observers and personnel, and financial resources are available.

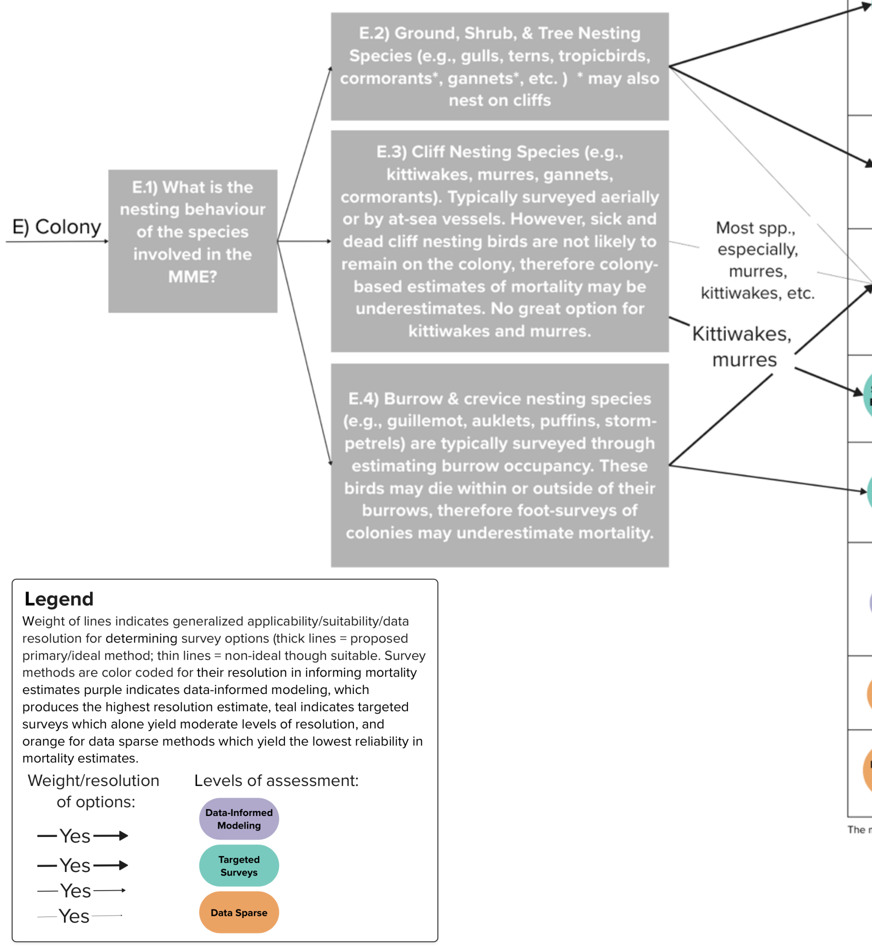
Fig. 4) **Decision tree D- Water detections:** Survey options for assessing mortality during mortality events involving carcasses detected in water include aerial at-sea survey and vessel at-sea surveys.

Colony Detections (Tree E)

Most marine birds are colonial, nesting in groups that vary in sizes and density across species and populations. Colonial breeding provides advantages, including group foraging, social stimulation, and predator defense. However, the proximity of nest sites can increase the transmission of infectious pathogens or parasites. Additionally, social behaviors can heighten the risk of mortality events due to pollution, climate events, and food stress, among others, when encountered by these gregarious marine birds. Considerations when determining the best assessment of mortality in colony breeding sites, where nests and breeding birds are closely aggregated, will vary greatly depending on the ecology and the nesting strategy of the species affected. Methods that are used for population monitoring in many colony nesting species may also be the most appropriate method to conduct mortality estimation at the colony site.

Marine bird colonies can be found in a variety of habitats though they can generally be divided into three primary types: i) ground, shrub, and tree colonies, ii) cliff colonies, and iii) burrow or crevice colonies (Fig. 5, E.2 -E.4). These groups are not exclusive as select species may implement different nesting strategies across populations in response to habitat availability. Taxa considered to be *'ground, shrub, & tree nesting species'* (Fig. 5, E.2) include larids (gulls and terns), cormorants, and gannets, among others. However, species such as cormorants and gannets may also nest on cliffs. *'Cliff nesting species'* (Fig. 5, E.3) include kittiwakes and murres. *'Burrow and crevice nesting species'* (Fig. 5, E.4) include shearwaters, storm-petrels, petrels, a number of alcids including guillemots, auklets, and puffins, etc.

Fig. 5) Decision tree E- Colony detections: Survey options for assessing mortality during mortality events involving mortality detected in colony settings. Options depend on the nesting behavior of species involved, including E.2) ground, shrub, and tree; E.3) cliff; or E.4) burrow and crevice directing the user to various survey options which may be broadly implemented and some which are often species specific



Survey Method	Description	Considerations
Aerial Survey	Use of distance sampling via strip transect where aircraft (helicopter, plane or drone*) flys over colony and trained observers count carcasses (*observers review recorded footage) on both side of the aircraft within a set perpendicular width using standardized protocols.	May be more appropriate for larger sized birds with contrasting plumage to the substrate, or where on foot colony visits will pose a significant disturbance to birds or present unacceptable OSH risks. If you conduct a shoreline/transect or beached bird survey at the same time you can then develop a correction factor*. Assumptions: Availability of deployable assets (helicopter, floatplane, drones) along with trained observers and personnel, and associated financial resources. The ability to distinguish live and dead birds. Pros: Larger areas can be surveyed rapidly. Can be used to survey colonies that are difficult to access, cliffs, islands, etc. or where disturbance impacts too great. Cons: Aerial surveys have reduced species identification accuracy if mixed species colony. Costly approach, unless using drones, that is challenging to rapidly mobilize. Not recommended for habitats with dense vegetation.
On-foot Colony Survey	In colony survey appropriate for any ground nesting species and is the only option for cryptic species (e.g., female eiders) or species that are not conducive to aerial survey detection. Survey methods include: complete/partial colony counts or colony transects depending on size of colony and capacity to assess.	Assumptions: Subsampling assumptions apply for partial colony surveys. Assumes entering the colony will not cause disturbance to birds or pose unacceptable OSH risk. Pros: Bird bands can be collected and carcasses can be removed or marked to prevent double counting & assess decomposition rates. Repeated surveys can provide valuable information on the progression of the mortality event. Cons: Must account for disturbance to the colony and OSH risks (PPE needed if appropriate).
At-sea Vessel Survey	Use of distance sampling via strip transect from an at-sea vessel where trained paired observers count on water carcasses below cliff colonies, identifying species, and following standardized protocols See Camphuysen et al. 2004 and Ronconi and Burger 2009 for more information.	Best option for cliff nesting species as carcasses do not remain on cliffs. Sinking may necessitate modeling of at sea loss. Drift may necessitate shoreline transects of beached bird surveys of nearby beaches. Assumptions: Birds can be easily observed on the water close to the vessel and before drift, wave action, and sinking occurs. Pro: Provides high accuracy of species identification. Cons: Requires prompt detections and activation of survey response due to carcass displacement/at-sea loss.
Shoreline Transects/ Beached Bird Survey	On foot survey methods. Shoreline transect or beached bird surveys (methods as above) of catchment beaches in the vicinity of the colony site(s).	Appropriate for many species where carcasses do not stay on colony sites such as cliffs. Data accuracy dependent on survey type and design along with skill of observers May be improved by incorporation of at-sea loss estimation (see above 'Drift modeling'). Pro: May be easier to access shoreline than water given conditions. Con: Cannot associate mortalities with a specific colony.
Burrow Occupancy Survey	Occupancy survey to assess adult survival/potential mortality and determination of nest abandonment (chick/egg failure). Occupancy surveys estimate population sizes by subsampling a plot of burrows, and can provide information on mortality if birds die in burrows or if nests are abandoned.	Assumptions: Mortality is assumed to be the cause of abandoned nests (chick/eggs). Subsampling assumptions apply Pros: Bands can be collected. Carcasses can be removed. Repeated surveys can provide valuable information on the progression of the mortality event. Cons: Requires access and capacity.
Demographic Analysis	Demographic analysis involves using detected moralities of marked individuals to estimate mortality and assess population impacts. By applying mark-recapture methods or N-mixture models researchers can refine survival estimates, account for detection probabilities, and quantify how mortality affects different age classes.	Assumptions: Appropriate for populations which are already monitored and where banding or other auxiliary markers have been used for survival analysis. Pros: Can provide robust estimates for mortality where not all mortalities are detectable. Cons: Requires previous years of monitoring.
Collate Reported Mortality	Collate mortality observations across all available sources (e.g., colony researchers, ecotourism operators, subsistence harvesters, governmental staff, iNaturaliist, public reports, etc.	Limited data accuracy. Data is limited to areas with human access. Pros; May not require site visit. May be less expensive. Cons: Requires staff capacity. Extent of mortality may not be fully detected/estimated.
Population Survey in the Following Year	Population monitoring including population trends and impacts on reproductive success in the year(s) following large mortality events may be used to estimate population declines.	This is the least recommended approach as it does not directly assess mortality. Cons: Changes in population size cannot be directly attributed to the mortality event. Requires population size assessments in the years directly before the mortality event. May be challenging to assess the MME impact if populations have high interannual size variation.

The most appropriate method may be the method that is already used to conduct population size assessments. Survey selection method may depend on resources available.

'Ground, shrub, & tree nesting species' (Fig. 5, E.2) can be surveyed using *'aerial surveys'*. *'Aerial surveys'* (discussed in detail above) can be used to estimate colony mortality using subsampling methods (strip-transects) or complete colony counts. Aerial colony surveys are most appropriate for larger bodied birds and those with less cryptic plumage. Colony mortality can be estimated using drones, such as in gannet colonies where mortality was estimated after HPAI shoreline carcass detections (Lane et al. 2023, Haman et al. 2024). Although, it may be difficult to reliably distinguish live versus dead birds. *'Aerial surveys'* may have reduced species identification certainty if it is a mixed species colony. Though *'aerial surveys'* can survey large areas in a short period of time they may increase disturbance to sensitive species which should be avoided during staging or breeding periods.

'Ground, shrub, & tree nesting species' (Fig. 5, E.2) colonies can also be surveyed via *'on-foot colony surveys'*, which can be conducted using complete colony counts or subsampling methods such as partial colony counts, or colony transects. The choice of method may depend on the colony size and the available resources for assessing a complete versus partial count.

When conducting colony surveys, counts of both live and dead birds should be taken, complete colony counts provide the most accurate estimate of population size and are particularly valuable if equivalent data are available from prior years, providing an estimate of average annual changes in population size (Haman et al. 2024). Subsampling methods can offer useful estimates for large colonies or where colonies may not be fully accessible due to habitat or limited resources. A benefit of colony surveys is that any bird bands (rings) or other auxiliary marks can be collected potentially providing individual-level information on mortalities. For populations that are intensively monitored, demographic analysis such as mark-recapture methods may provide more refined estimates of mortalities, such as Marbled murrelets (Raphael et al. 2007). Additionally, for populations or colonies with previous estimate sizes the proportion lost can be estimated by 'aerial surveys'. Using age-related survival analyses from previous years, researchers may use recovered bands to estimate mortality using deviations in survival patterns. Future colony counts can be used to verify mortality estimation efforts made post-mortality events and help assess long-term population impacts.

Benefits of on-foot colony surveys include the ability to identify cryptic species (e.g., female ducks) and collect bird band or other auxiliary markers. Marked carcasses may be left on colony or removed to prevent double counting. Marked carcasses can be further evaluated for carcass persistence rates. This is particularly useful if later aerial surveys will be used in conjunction with initial on-foot surveys. Aerial photographs allow for fitting point process models even when detections are rare which is suitable for carcass detection when at sea-carcasses exhibit high loss or carcasses have low persistence (as in McDonald et al. 2021).

If the cause of mortality is infectious disease or toxicological in nature, marking carcasses may not be appropriate due to increased colony health risks. Removing carcasses may be useful but requires additional capacity and planning in collaboration with the proper authorities for disposal. Removing carcasses may make future counting more feasible, particularly for cases of chronic mortality events. If the mortality cause is an infectious zoonotic pathogen, such as HPAI virus, additional considerations must be taken into account such as occupational safety and health risk (OSH) and the need for appropriate PPE for staff.

For species that are highly sensitive to disturbance during the breeding season, '*aerial surveys'* via drones may be less invasive to estimate colony size and detect mortality. Regardless of the method uses, surveys should consider the potential for disturbance to birds and nest success.

‘Cliff nesting species’ (Fig. 5, E.3) are difficult to survey for mortality as carcasses generally fall off cliff faces though this depends on the topography of the cliff site (i.e. distance from water, distance from cliff edge) and the specific species. Cliff-nesting species are exposed to wind and atmospheric conditions and therefore are more susceptible to mortality from extreme storms and other weather events (Newell et al. 2015). Most cliff colonies are monitored/surveyed from the water, using at-sea-vessels or aircraft, usually helicopters or drones, due to the difficulty of accessing cliff sites. Few cliff colony sites are low enough or safe enough to allow for cliff access. For these reasons ‘cliff nesting species’ (Fig. 5., E.3) can be surveyed using ‘shoreline transects’ or ‘beached bird surveys’ to assess mortality at shorelines in the surrounding area by detecting catchment beaches, where large amounts of debris and carcasses are deposited. ‘*Burrow and crevice nesting species*’ Fig. 5, E.4) mortalities may be detected within the colony site, though this is rare, and carcasses are more commonly found washed ashore. For in colony mortalities ‘*burrow occupancy surveys’* may be carried out. Burrow occupancy can be estimated using subsampling or transect methods (Reid et al. 2013). If burrow is not too deep an endoscope may be used to check for occupancy or sight carcasses if adults may have died within the burrow, though proclivity to die within the burrow may be species specific. Otherwise, burrows are checked for chick/egg failure to determine mortality related abandonment. Burrow surveys assume that mortality of the adult is the cause for abandonment. Migratory bird bands may be collected from carcasses and can help with identification of colony of origin. Otherwise, burrow occupancy must be known a priori and playback maybe used to determine active burrows.

‘*At-sea Vessel Surveys*’ may be undertaken to assess mortality at all three colony nesting types, E.2) ground, shrub, and tree colonies, E.3) cliff colonies, and E.4) burrow or crevice colonies (for limited numbers of species which may have a propensity to die at sea). However, this method may be less appropriate than those mentioned previously, depending on the cause of the mortality, the distribution of mortalities, and species-specific characteristics (e.g., cliff-nesting species for which carcasses are not often detected on colony sites). At-sea surveys for estimation of in-colony mortalities may be less effective and yield underestimates.

If no immediate survey methods are possible during and shortly after the mortality event, then it is possible to 'collate reported mortalities' (as described in above section *Shoreline detections, Tree C*). Lastly, '*population surveys in the following year*' can be conducted to assess trends and demographics as well as reproductive success post hoc. When previous years data are available, deviations from prior estimates can be used to inform population declines, but they cannot be used to directly estimate mortality or correlate it to a single event. Mortality estimates based on before/after comparison of bird colony breeding populations or at-sea live bird densities are possible but are generally challenging and ascribing any change in population size to a particular event usually requires numerous assumptions. The exception is for an intensively monitored colony where the major drivers of population change are known, in this case that year-to-year variability can be modeled, and additional mortality can be reliably attributed to the mortality event. An understanding of population trends requires long term intensive monitoring to be certain trends are not regular stochastic processes of populations with high interannual variations.

Discussion

The objective of the decision tool presented within this product is to help managers determine appropriate survey methods to best estimate losses during marine bird mortality events. This decision tool assists with identifying decision points, setting priorities, and selecting appropriate methods for estimating marine bird losses, considering context such as location of detection, the temporal and spatial extent of the event, species affected, and the resources available to help the manager collect and/or collate data. In some cases, multiple survey methods may be needed. For example, Jones et al. (2019) describe the implementation of COASST program data and drift particle modeling, while Haman et al. (2024) detail the use of aerial surveys and carcass removal/counts, Avery-Gomm et al. (2024) combined reported mortalities from various sources, incidental observations, and standardized surveys. The suite of potential approaches represents a spectrum of methods that can be used *individually or in conjunction* to at a minimum collect standardized information to better describe unusual mortality events based on opportunistic reporting that can produce scientifically rigorous mortality estimates. The selection of approaches depends on several additional considerations, including site accessibility (i.e., remoteness, access points), worker health and safety, existing monitoring or census population methods, existing infrastructure to collate mortalities, existing capacity and pipelines for diagnostic testing, and timeliness of reporting sick and birds to the decision-making manager.

All subsampling survey methods rely on good survey design and numerous assumptions. These include that the sampling strategy (e.g., strip, line, point counts) accurately represents the overall affected area and that transect placement is random within the study area (Strindberg et al. 2008, Buckland et al. 2015). Additional assumptions include that all carcasses within the transect or on the transect will be detected, though this assumption may be relaxed depending on the analytical method (Miller et al. 2019). If observed distances from the transect are recorded, a detection function can be developed that characterizes the probability of detecting mortalities given some distance from the transect (Miller et al. 2019). Survey design is outside the scope of our discussion, however methods that incorporate geographical information for transect surveys such as packages ‘dsims’ and ‘dssd’ (Marshall 2023a, b) implementable in R (R Core Team 2021) can automate survey design.

Several strategies can be employed to increase the probability of detecting marine bird mortality events when detection is likely opportunistic. Enhancing detection efforts involves conducting more intensive beached bird surveys, particularly on high-energy beaches where carcass retention is reduced. Expanding the spatial extent of surveys can help identify the full range of events and potential spread to adjacent areas. Additionally, focusing on sensitive and sentinel species can help provide early detection or detection of secondary events. Implementing systematic surveys, such as beached bird surveys, can improve the chances of detecting mortality events early, thereby allowing for quicker response to mitigate further impacts. For example, the COASST community science-based monitoring program provides data exploration from 1999 to present, allowing for monitoring of changes in mortality detection and identification of significant outlier events and trends such as the impact of marine heatwave events on marine bird species (Piatt and Van Pelt 1997, Jones et al. 2024). Additionally, improving outreach and engagement with local communities, informing them of the best reporting channels and providing education on what should be reported can encourage the growth of timely reporting. Improving the engagement and use of community science platforms and programs may have the broadest potential to increase detections and reporting.

The implementation of a well-coordinated mortality event response is highly challenging due to the complex logistics and resources that must be rapidly mobilized. To overcome this, forward looking planning is essential, including the integration of community science initiatives and reporting tools with efforts of governmental, research, NGOs, and rehabilitation centers. Resources and capacity are often a significant limitation, in executing timey responses. However, proactive planning can mitigate these challenges by ensuring response plans are in place, funds are allocated in advance, and that resources can be strategically leveraged across jurisdictions when necessary.

The carcasses that deposit on shorelines likely constitute a fraction of the total mortalities that occur at sea. At sea, mortality events may result in a majority of carcasses sinking with only a proportion depositing on shore, though this proclivity is species specific. Of the carcasses deposited on shore, many may be scavenged or buried in sand/debris before detection. Therefore, collecting mortality data and diagnostic sampling (i.e., swabs, tissues, photographs, and carcasses for necropsy) may be necessary to identify the underlying cause and assess the species affected and potential population-level repercussions. Deposition rates of carcasses will vary with species, location, and climate conditions. With appropriate data collected and available (e.g., ocean current, wind direction, sinking rates), mortality can be modeled, using 'drift modeling to estimate at-sea loss' and more accurately estimated.

Although the decision tool explicitly addresses the spatial scope of the event, it does not consider how events that extend over a prolonged period may require repeated follow-up surveys to accurately estimate mortality. For extended events, accuracy of total mortality estimation will be influenced by the cause of the mortality event, typically assessed during the *Initial Mortality Assessment*. Chronic events may necessitate follow-up surveys or long-term monitoring. The cause of a mortality event informs the most appropriate survey approach, influencing where carcasses are deposited or detected and the event's duration. For example, if the cause of death is chronic (e.g., uncontrolled oil release), resources (financial, human and deployable assets, such as helicopters, planes, sea vessels) may need to be managed strategically or additional resources secured for repeated surveys as the event progresses. Disease outbreaks, such as HPAI and avian cholera, and impacts from food resource limitations may be acute or chronic, whereas catastrophic oil spills, windstorms, and botulism are always acute and may require fewer surveys over time. Site accessibility will vary across jurisdictions as will the deployable assets, human resources, and financial resources needed to reach remote sites. Additionally, site availability may correlate with how often a population or area is censused or monitored, informing the most appropriate survey method.

Large-scale mortality events, characterized by their spatial or temporal extent and the number of mortalities, may benefit from implementing multiple survey methods to achieve accurate estimates (e.g. '*Aerial survey*' and '*shoreline transects*' or '*beached bird survey*' and '*collate reported mortality*'). Chronic events with no clear end date may require careful resource allocation, budgeting for additional surveys, and sustained financial support. Ongoing efforts can be leveraged for mortality estimation where available; for example, where 'aerial' or 'vessel at-sea' surveys for live marine birds are already underway, the density of dead birds can also be estimated (Giralt Paradell et al. 2023). The most appropriate combination of methods is situationally specific and dependent on resource availability. However, using multiple approaches can significantly enhance the accuracy of mortality estimates. The precision of these estimates varies based on the methods and surveys conducted. It can range from sparse, opportunistic data with lower accuracy and inherent bias (i.e., public reporting and scoping, collation of reported mortalities), to targeted survey estimates, which incorporate one or more survey methods, to data-informed modeling that incorporates various survey methods, data types, and correction factors to inform a comprehensive mortality estimate model.

Marine bird mortality surveys often result in inherently messy data, characterized by various and often non-standardized survey methods and partial datasets, which may at times render frequentist statistical approaches less appropriate. Other methods should be considered as appropriate, for example Bayesian approaches offer a framework for estimating uncertainty. Techniques such as hierarchical modeling enable analysis of mortality with inherent variability in survey data and incomplete datasets, providing a more accurate estimation for mortality rates. Bayesian approaches allow for the incorporation of prior knowledge and the integration of different data sources (e.g., public reports, beached bird survey, aerial survey) and prior population data, where appropriate, better accounts for uncertainty and shares information among datasets to improve estimates (Avery-Gomm et al. 2024). Bayesian methods offer flexibility with complex datasets that have associated high uncertainty. They can be used to model factors such as detection probabilities and observer bias if the data are gathered appropriately. Although varied statistical approaches offer distinct advantages, they may require the inclusion of a skilled quantitative biologist from the outset. Additionally, identifying the end user of data from the outset ensures that the data collection and survey design follow best practices, and that the data are usable whether frequentist, Bayesian, or other statistical methods are employed.

In summary, our decision tool provides a comprehensive framework to help managers in determining the most appropriate survey methods for estimating mortality. By considering the location of the mortality detection, the extent of the event, and assessing available resources, a manager can determine whether initial assessments or a suite of tailored follow-up survey methods are needed to achieve, when possible, scientifically rigorous mortality estimates or other best possible options, such as existing report collation or additional scoping of mortality. By leveraging existing monitoring efforts and ensuring thorough data collection including public reporting and scoping we can better understand the causes and scale of impacts of marine bird mortality events, ultimately informing conservation and management strategies. This holistic and adaptable approach seeks to aid the incorporation of mortality estimation into response plans and help strengthen the capacity and support for mortality response across jurisdictions with varying resource availability. A lack of robust data collection could inhibit our full understanding of marine bird mortality at both landscape and species levels, reducing the effectiveness of conservation strategies and leaving potential gaps in marine ecosystem management.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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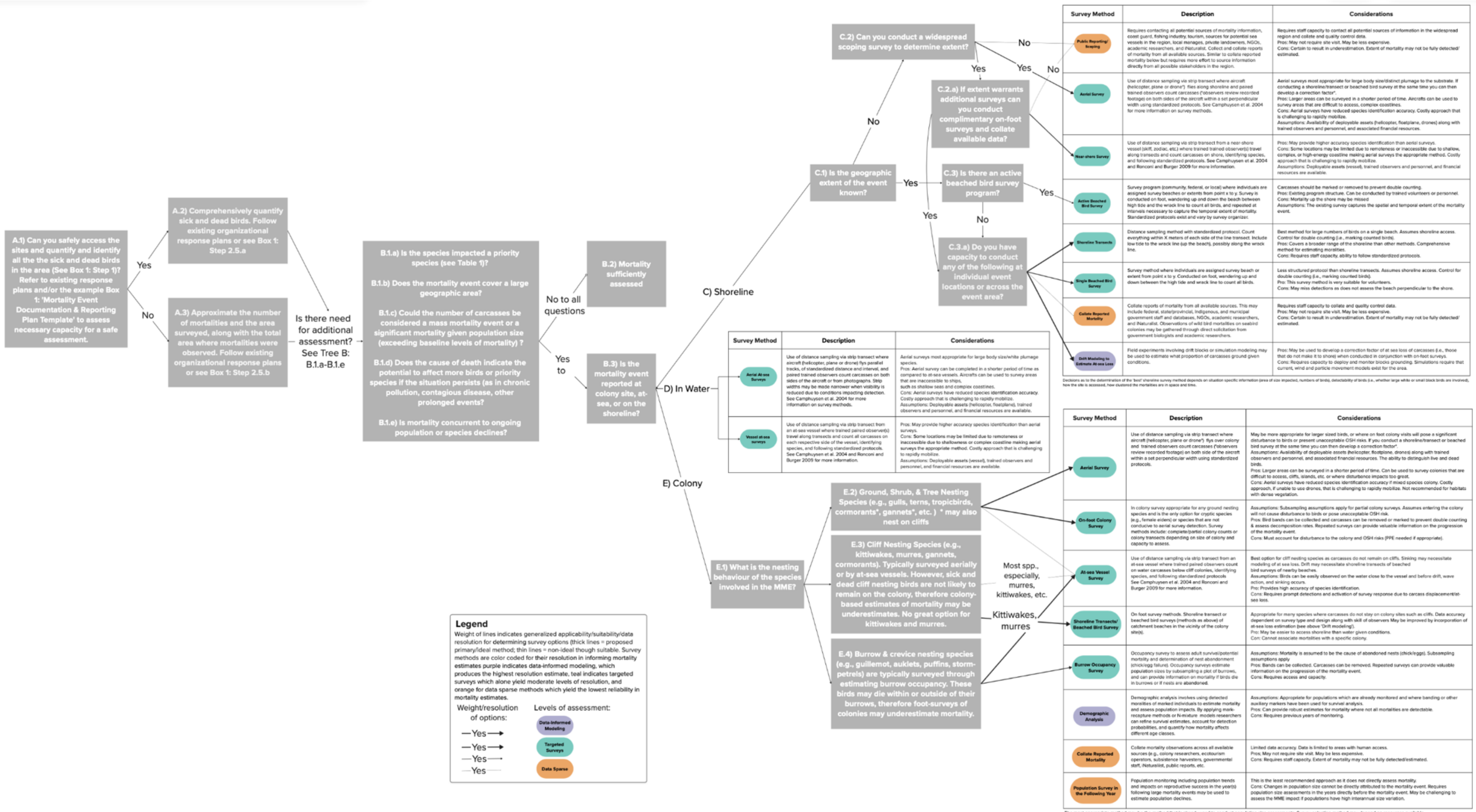

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867 **Supplemental Figure 1**) Full decision tool to aid managers in identification of the best survey practices for marine bird mortality

868 enumeration given location, species specifics, and potential constraints.